Pienu Overview and Update

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Outline

- Brief description of the experiment
  - Reminder: the goal of Pienu is to measure
    $$BR = \frac{\pi \to e\nu(\gamma)}{\pi \to \mu\nu(\gamma)}$$ to 0.1%
  - schematic of the detector
  - triggers and special runs
- Status of the analysis
- A list of previous presentations is in the Appendix
  - (apologies to those who have seen the previous talks)

The Pienu Experiment at TRIUMF

Beam:

60kHz pions @ 75 MeV/c

$\pi : \mu : e = 85 : 14 : 1$

Detector: [1]

Acceptance: 20%

Plastic Scintillators

NaI(Tl) + CsI Calorimeter

Wire Chambers

Silicon Strips

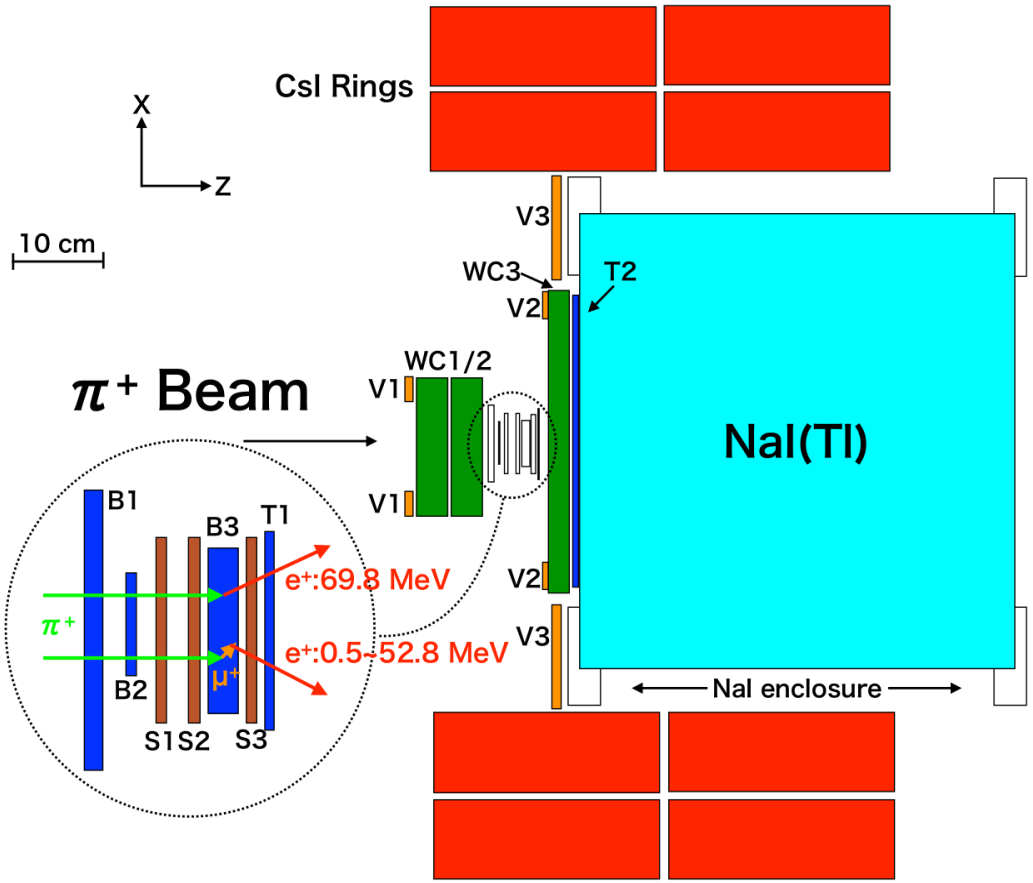
Energy resolution:

2.2% FWHM @ 70MeV

Temperature Stabilization

Data taking:

2009-2012



[1] A. Aguilar-Arevalo et al., Nucl. Instrum. Methods Phys.Res., Sect. A 791, 38 (2015).

Triggers

- The physics trigger = incoming pion*outgoing positron

  $B1 \cdot B2 \cdot Tg \quad * \quad T1 \cdot T2$

- Physics triggers:

	rate (Hz)	purpose
– Early (5-40 ns)	160	enhance $\pi \rightarrow e\nu$
– Prescale (1/16)	170	unbiased
– TIGC (E>~48 MeV)	240	enhance high energy

- Other triggers:

– Ecalib (beam positrons)	2	counter calibrations
– XeTrig	2	gain monitor
– CsISum (cosmics)	15	CsI calibrations

Special datasets

- In addition to the primary physics data with simultaneous support triggers, several special datasets were interspersed, including:
  - positron beam for the tail fraction
  - T1 and T2 inefficiency
  - muon runs for the t0 correction
  - beam momentum scans for the pion stop location
  - cosmic-ray runs with beam off
  - positron-beam momentum scans

Status of the Analysis (part 1)

- Analysis of the primary data has been stable for some time
- Additional early data with Bina only is under analysis
  - the acceptance is restricted due to shower leakage at larger angles
- The muon decay-in-flight correction has been reevaluated yielding a substantial change in the result

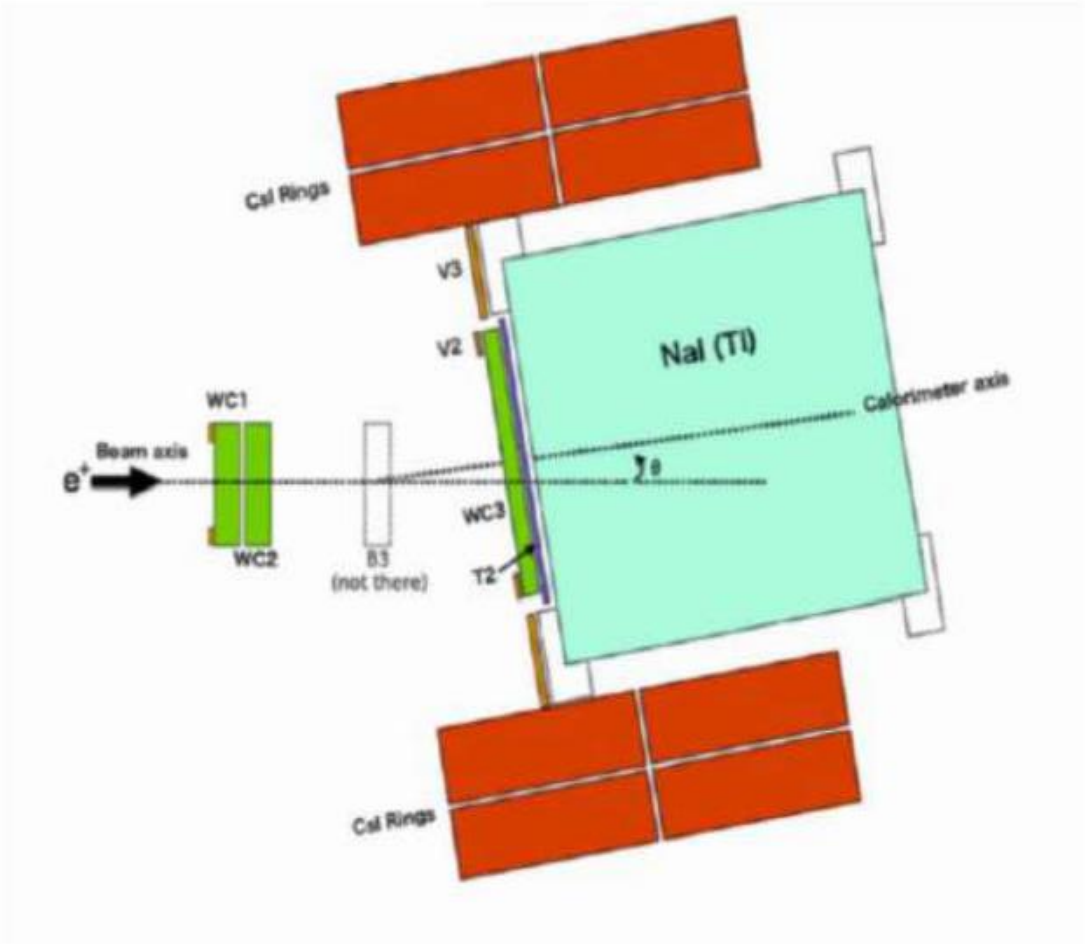
Status of the Analysis (part 2)

- High statistics MC files are being generated
  - necessary to study the acceptance correction
- Thus far, all systematics checks have been passed successfully (BR vs R, BR vs Ecut, Ntrk = 1, etc.)
- Evaluation of systematic uncertainties continues to be refined as we prepare to unblind the result

Importance of the Lineshape data

- There are two versions of the Pienu MC:
  - Primary MC: is intended to reproduce the Pienu detector with an incident pion beam ($\pi \rightarrow e\nu$ and $\pi \rightarrow \mu\nu \rightarrow \mu e\nu\nu$ modes are run separately)
  - Lineshape MC: used an incident positron beam with most detector elements upstream of the calorimeter removed (so the calorimeter could be rotated)
- By matching the Lineshape MC to data, the calorimeter response from the primary MC can be validated

Positron Beam Data



70 MeV/c positron beam

Many detector elements removed: B1, B2, Tg, T1, S1, S2, S3

Data taken at ten angles

Tail fraction increases significantly as a function of angle

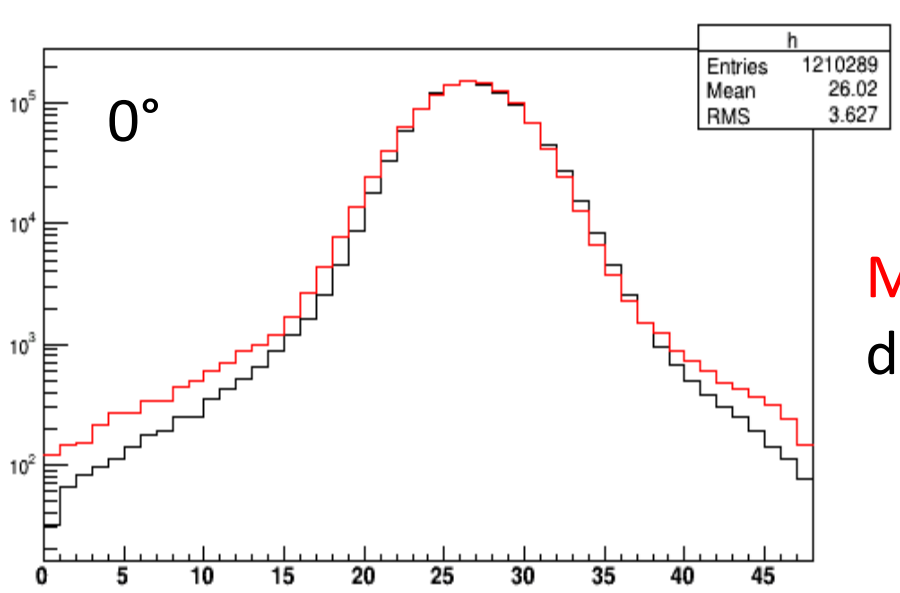
Requires clean positron beam: PIENU beam had ~1% momentum spread, low-energy tail intrinsic to beam <= 0.01%

Improvements to the Lineshape analysis

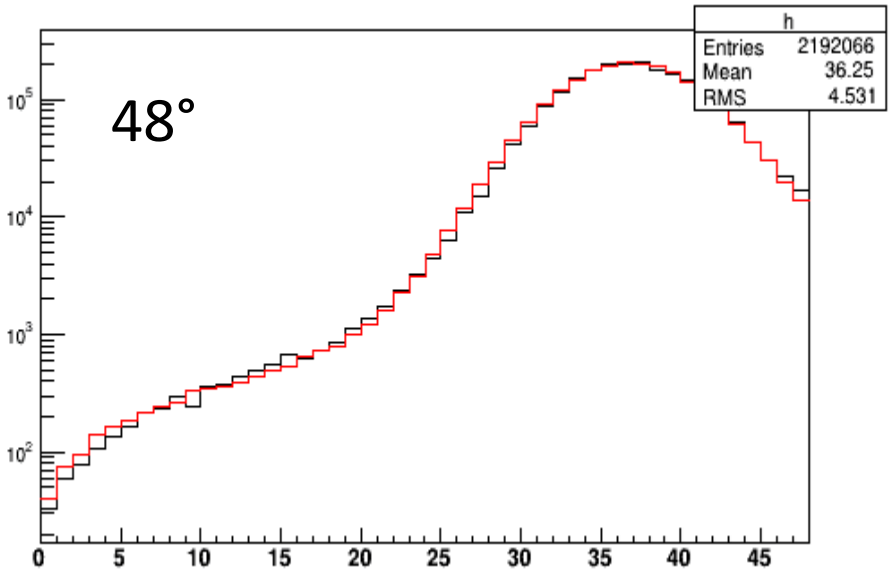
- Refinements in the data analysis have improved the quality of the result and slight changes in the measured tail fractions
- Much effort has been invested this year to better match the MC for the Lineshape to the data
- One example is to include material previously neglected, e.g. the beam vacuum window
  - this improved the agreement for the tails of the spatial distribution, which is most important for 48° due to shower leakage

Match of MC to data

- A comparison of the spatial distributions of events for MC and data is shown for the smallest (0°) and largest (48°) angles
- WC3 is the wire chamber just upstream of Bina



MC
data



WC3_X

Physics Lists in Geant4

- There was a long-standing problem that different versions of Geant4 yielded different values for the tail fraction.
  - an earlier version of Geant4 (9.6) agreed better with the data
  - a more recent version (10.2), with presumably improved EM physics, gave results significantly larger than the data at forward angles.
- We have now upgraded the MC to version 10.06, which allows a choice of EM models

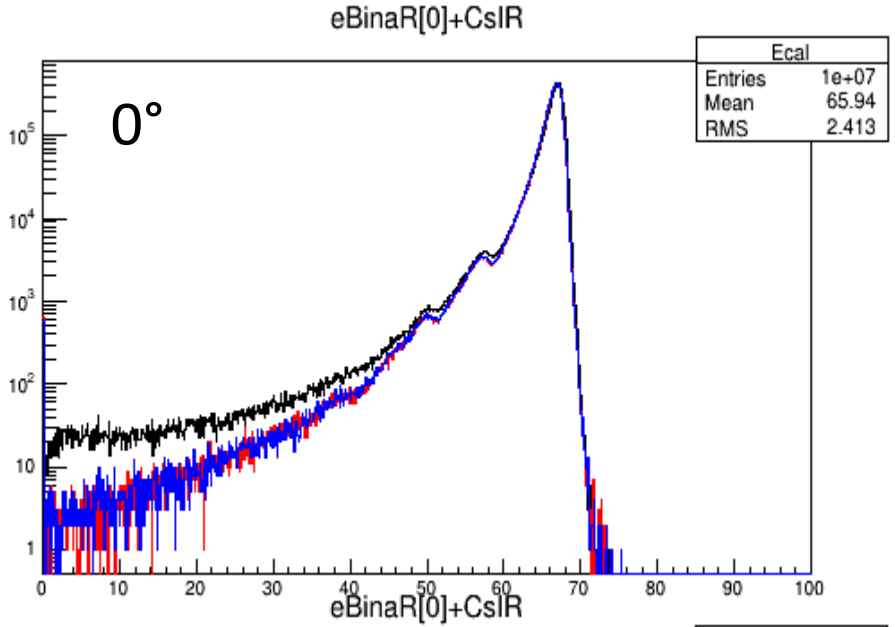
Compare EM physics versions

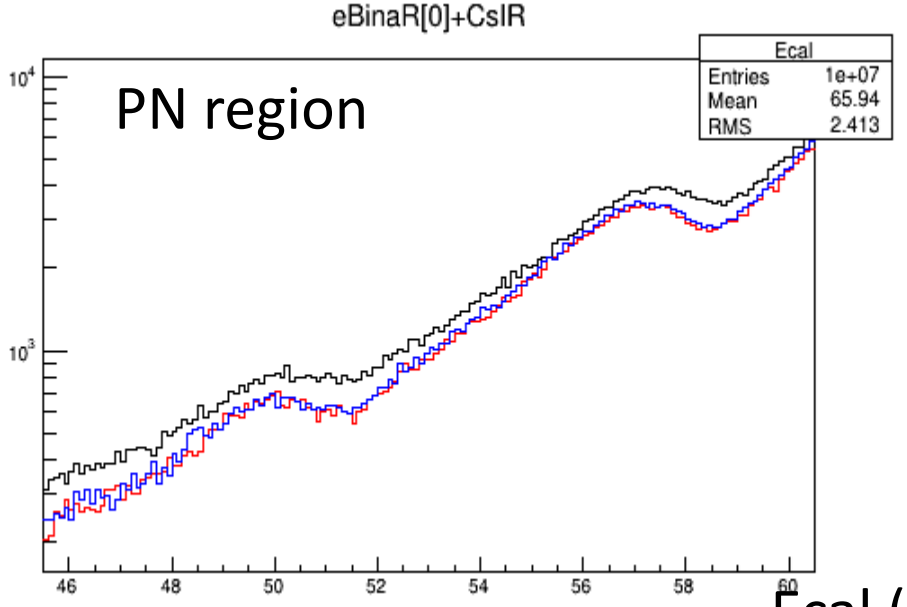
- EM physics in Geant4 has multiple choices available
  - opt0: default, which used the Urban model for multiple scattering
  - opt4: ≡ EMZ means that the default electromagnetic physics is substituted by the configuration providing the most accurate simulation of electromagnetic physics, including the GoudsmitSaunderson model for multiple scattering
  - Penelope (Penetration and ENErgy LOss of Positrons and Electrons) is a a general-purpose Monte Carlo code system for the simulation of coupled electron-photon transport in arbitrary materials. PENELOPE covers the energy range from 1 GeV down to, nominally, 50 eV.

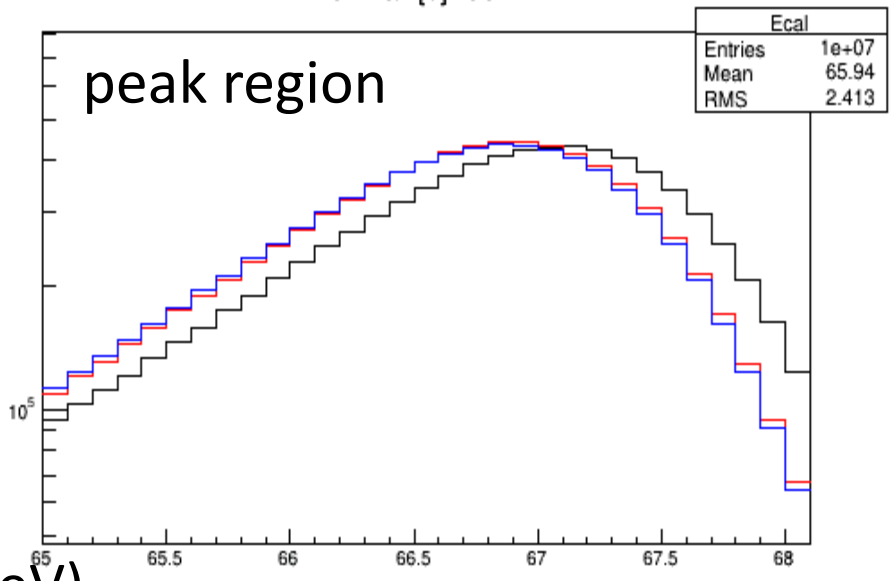
Compare Physics Lists

0° mf = 1.5 no cuts

	tail fraction
QGSP_BERT	0.0083
FTFP_BERT_PEN	0.0057
FTFP_BERT_EMZ	0.0060







Ecal (MeV)

Appendix

Previous presentations

- On DocDB
  - Trigger Overview 20Aug21 Tristan
  - Pienu Overview 22Feb22 Tristan
  - Systematics for the Pienu Analysis 1Mar22 Dick
  - follow-up Discussion Google Doc 5Mar22 Dick
  - Monte Carlo versions for Pienu 6Sep23 Dick

- Rare Pion Decay Workshop Santa Cruz (6Oct22)
  - Systematics from old muons Dick
  - Tail Correction and Muon Decay-in-flight Tristan